US 20170283975A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2017/0283975 A1
(43) Pub. Date: Oct. 5, 2017
LI

(54) PATTERN TRANSFER DEVICE AND PATTERN TRANSFER METHOD

(71) Applicant: KABUSHIKI KAISHA TOSHIBA, Tokyo (JP)

(72) Inventor: Yongfang LI, Kawasaki (JP)

(21) Appl. No.: 15/262,977

(22) Filed: Sep. 12, 2016

(30) Foreign Application Priority Data

Mar. 29, 2016 (JP) 2016-065741

Publication Classification

(51) Int. Cl.
C25D 11/32 (2006.01)
C25D 21/12 (2006.01)
C25D 17/00 (2006.01)
C25D 9/06 (2006.01)
C25D 7/12 (2006.01)

(52) U.S. Cl.
CPC ***C25D 11/32*** (2013.01); ***C25D 9/06*** (2013.01); ***C25D 7/12*** (2013.01); ***C25D 17/007*** (2013.01); ***C25D 21/12*** (2013.01)

(57) ABSTRACT

According to one embodiment, a pattern transfer device includes a substrate, a transfer unit and a controller. The transfer unit is configured to have electrodes and transfer a pattern corresponding to the electrodes with a voltage applied between the substrate and the electrodes. The controller is configured to control humidity between the substrate and the transfer unit.

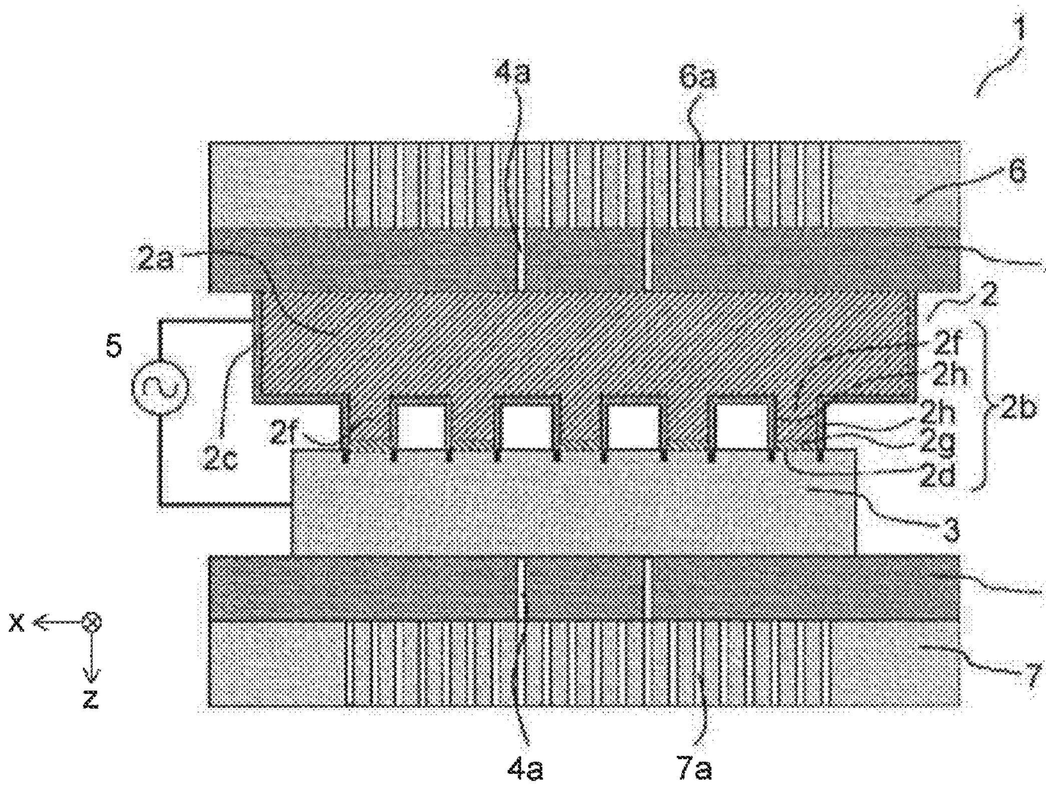


FIG.1

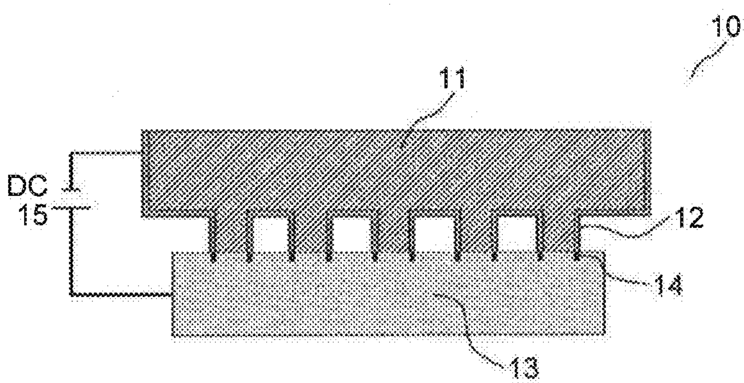


FIG.2A

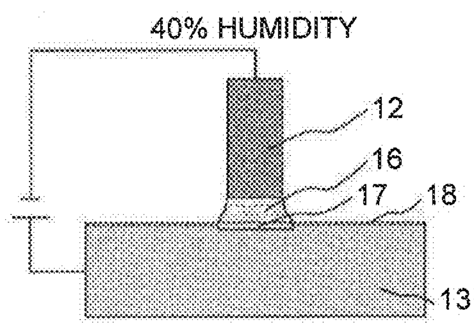


FIG.2B

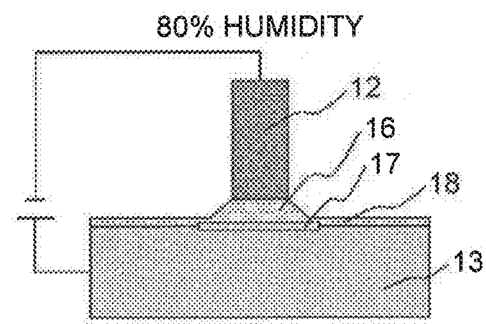


FIG.3

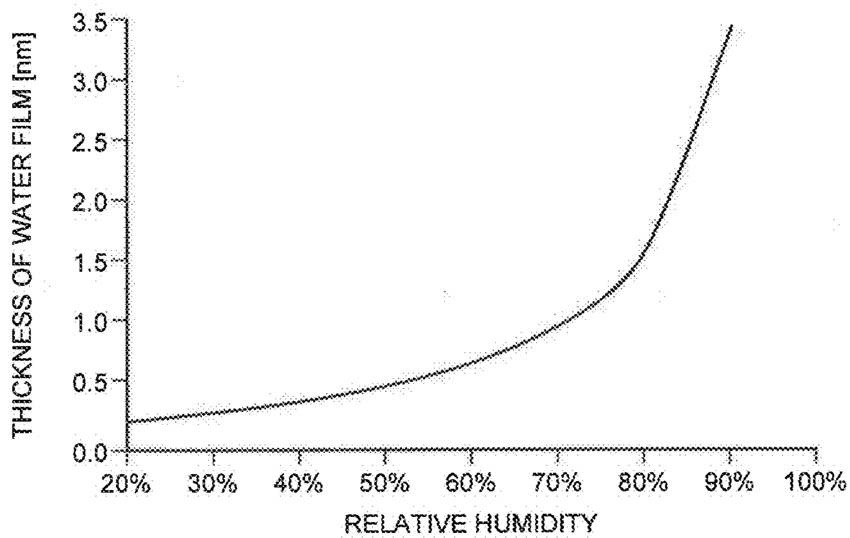

THICKNESS OF WATER FILM [nm]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
20%
30%
40%
50%
60%
70%
80%
90%
100%
RELATIVE HUMIDITY

FIG.4

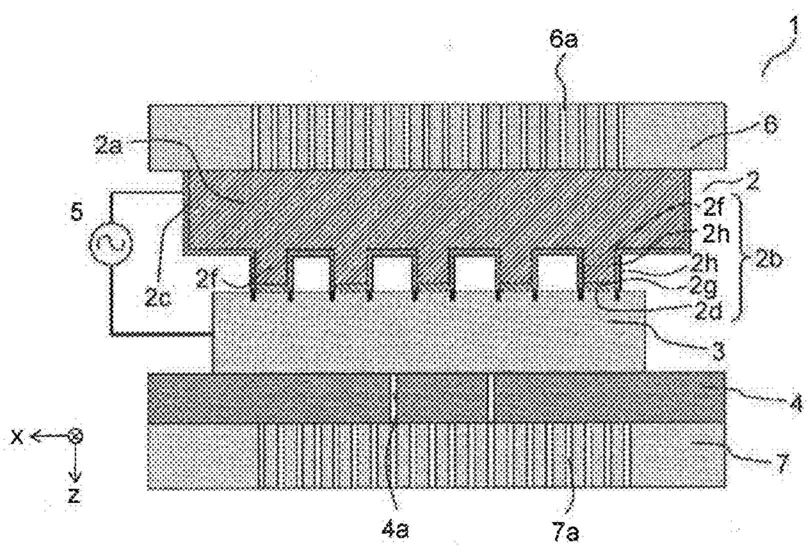

6a
1
6
2a
2
5
2f
2h
2b
2c
2f
2h
2g
2d
3
4
x
z
7
4a
7a

FIG.5

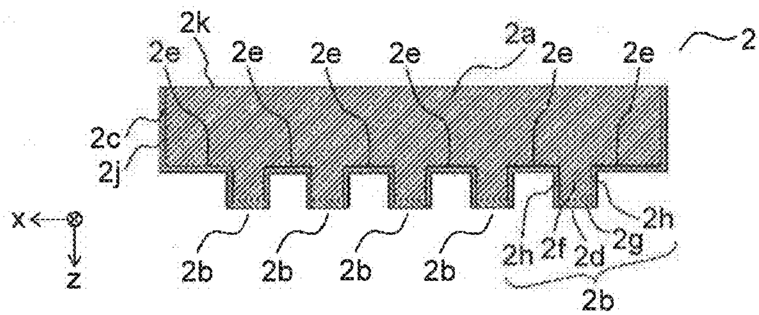

2k
2e
2e
2e
2e
2a
2e
2e
2
2c
2j
x
z
2b
2b
2b
2b
2h
2h
2f
2d
2g
2b

FIG.6

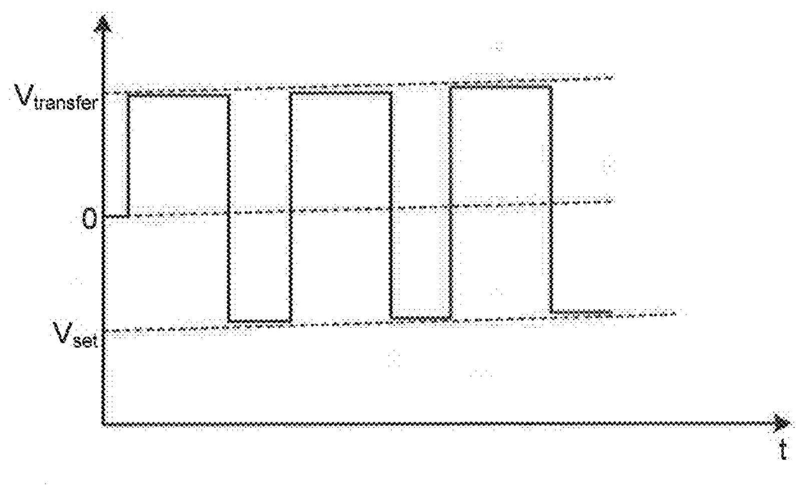

$V_{transfer}$
0
V_{set}
t

FIG.7A

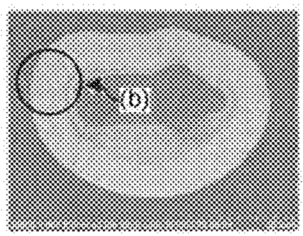


FIG.7B

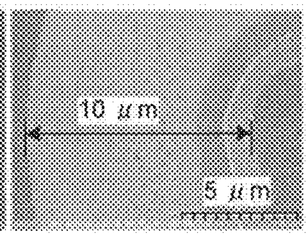


FIG.7C

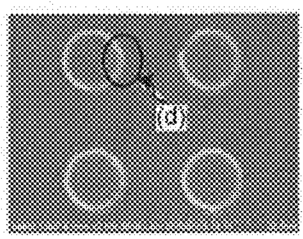


FIG.7D

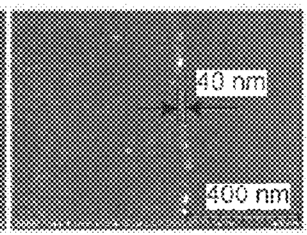


FIG.7E

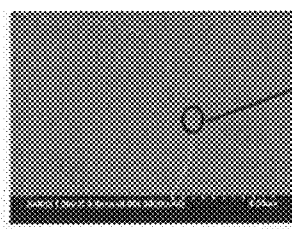


FIG.7F

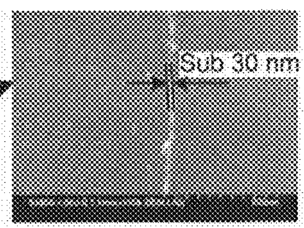


FIG.8

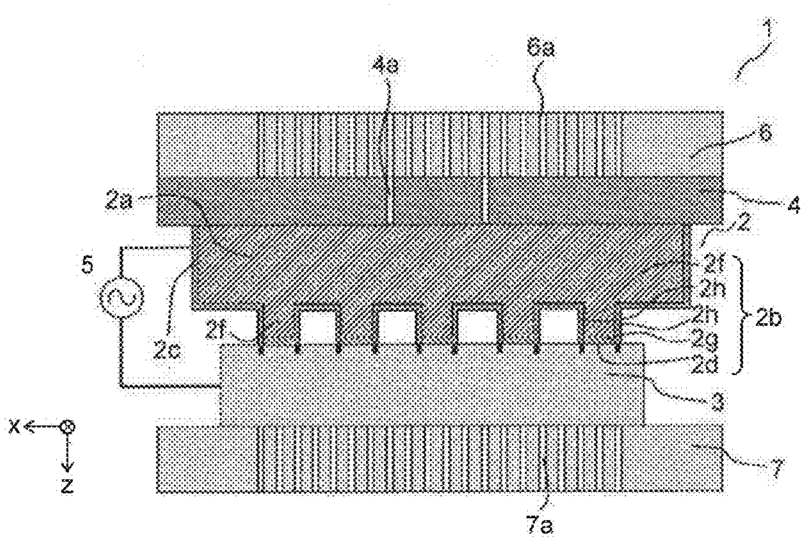


FIG.9

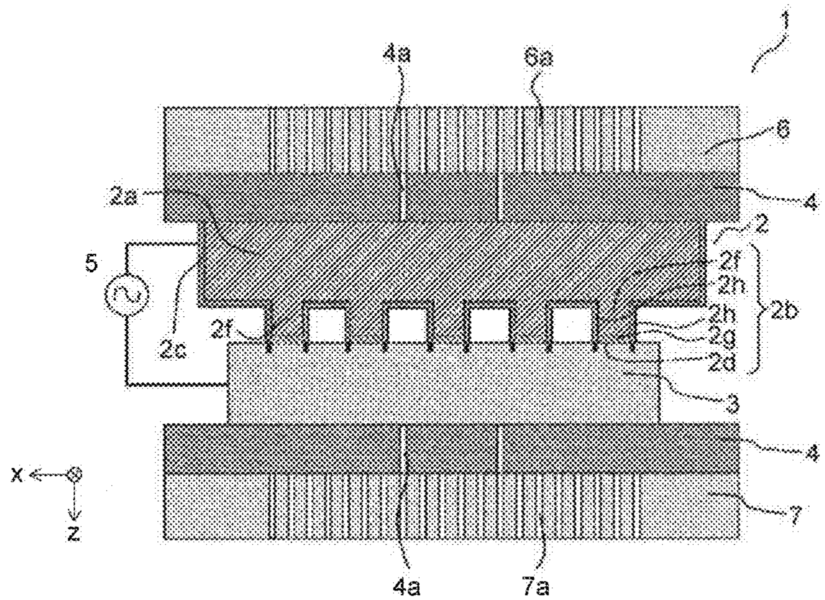

1
4a
6a
6
2a
4
2
5
2f
2h
2b
2h
2c
2f
2g
2d
3
4
x
z
7
4a
7a

FIG.10

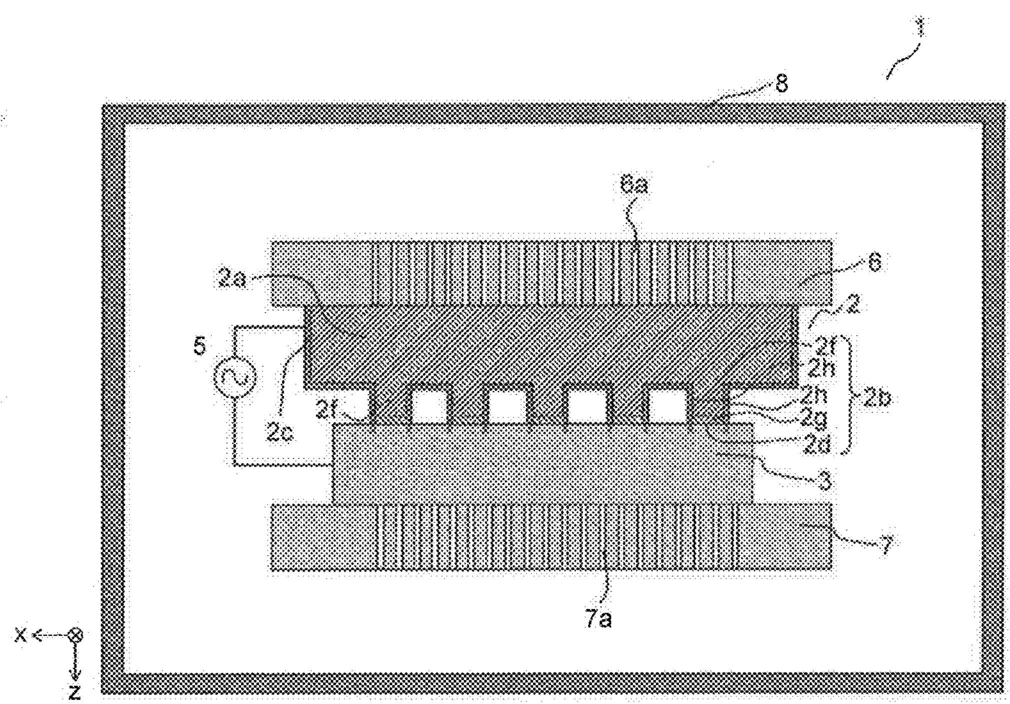

1
8
6a
2a
6
2
5
2f
2h
2b
2h
2c
2f
2g
2d
3
7
7a
x
z

FIG.11

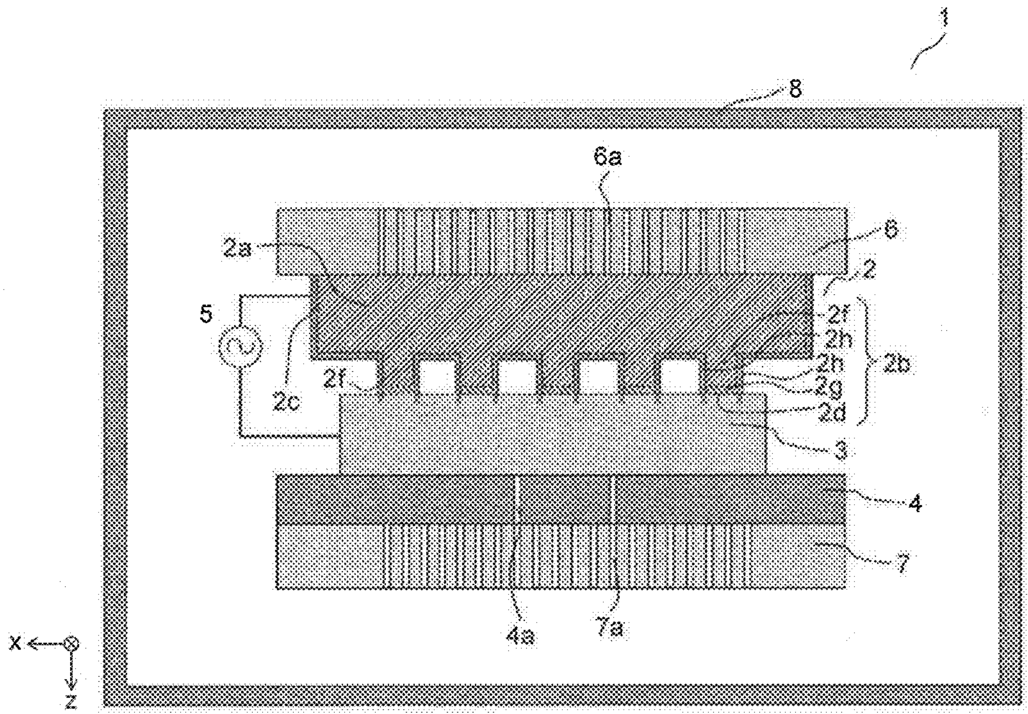

1
8
6a
6
2a
2
5
2f
2h
2b
2f
2c
2h
2g
2d
3
4
7
4a
7a
x
z

FIG.12

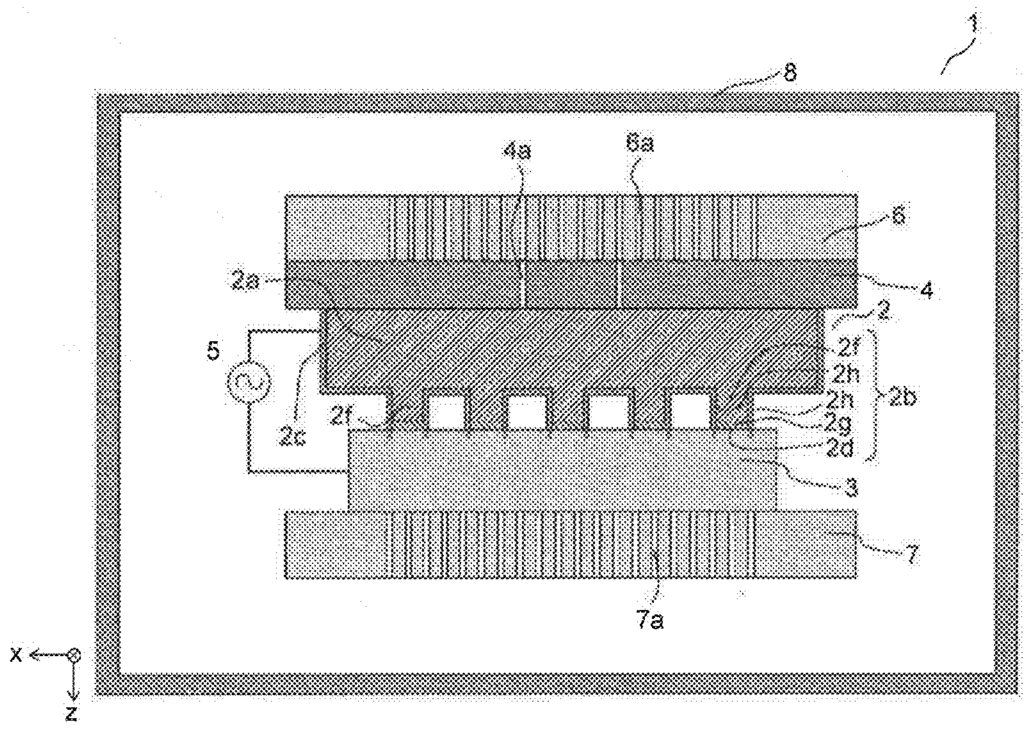
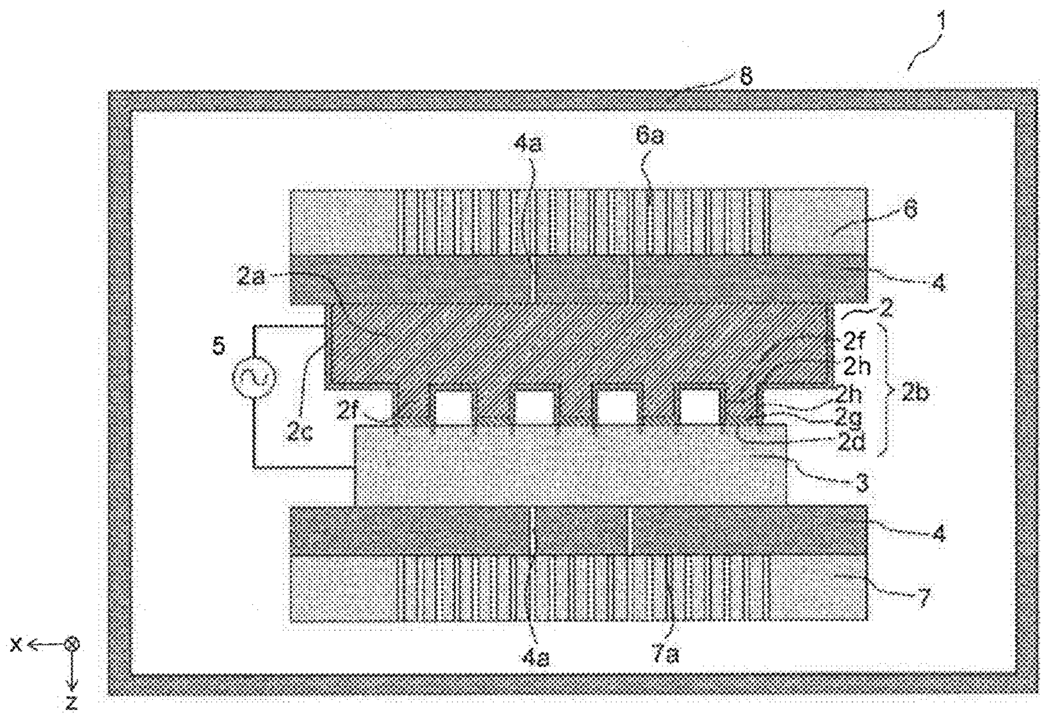

1
8
4a
6a
6
2a
4
2
5
2f
2h
2b
2c
2f
2h
2g
2d
3
7
7a
x
z

FIG.13



PATTERN TRANSFER DEVICE AND PATTERN TRANSFER METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2016-065741, filed on Mar. 29, 2016; the entire contents of which are incorporated herein by reference.

FIELD

[0002] Embodiments relate to a pattern transfer device and a pattern transfer method.

BACKGROUND

[0003] Semiconductor devices have increasing requirements for miniaturization and reduction in fabrication costs.

[0004] One of the promising next-generation lithography technologies is nanoimprint lithography (NIL) that can transfer nanometer-scale pattern with low fabrication costs. In nanoimprint lithography, the size of a pattern on a master mold defines the pattern transfer resolution. To transfer a high-resolution pattern, a mold with a very fine pattern is needed, thereby increasing the fabrication costs. In addition, uniformity of the residual layer and processing on the residual layer still need to be considered. To solve the problems above, a novel sidewall nanoelectrode lithography method has been developed. This method is a resist-less method and allows high-resolution pattern transfer that is not restricted to the size of the pattern on the master mold.

[0005] The sidewall nanoelectrode lithography uses nanoelectrodes formed on sidewalls of an insulating pattern on an insulating mold, and causes voltage and current to be applied between the sidewall nanoelectrodes and a transfer substrate to electrically transfer a pattern corresponding to the form of the sidewall nanoelectrodes onto a substrate. Sidewall nanoelectrodes having a thickness of a few nanometers can, in principle, transfer a nanometer-scale pattern as a whole corresponding to the size of the sidewall nanoelectrodes. Unlike the conventional nanoimprint technology, this method can transfer a finer pattern than the convex pattern formed on the mold. The sidewall nanoelectrode lithography is also advantageous over a probe lithography in that it can achieve higher throughput. The sidewall nanoelectrode lithography is a resist-less method and thus can avoid problems relating to, for example, the residual layer in nanoimprint lithography.

[0006] A transferred pattern fabricated by this method normally has a thickness of about sub-nanometer to 10 nm. Such a transferred pattern, when used as an etch mask, fails to satisfy a thickness requirement of several tens of nanometers or more in the etch process. When the transferred pattern is used as an etch mask in fabricating a multi-purpose fine pattern, the transferred pattern is preferably a thicker pattern with a thinner linewidth. In other words, a transferred pattern with a high aspect ratio is desired. However, due to some environmental factors such as humidity and temperature in a pattern transfer process, a thick contiguous water film is formed over the surface of the substrate and a large meniscus is formed at a transfer unit, which prevents high-resolution pattern transfer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a diagram illustrating a pattern transfer device for nanoimprint lithography including sidewall electrodes;

[0008] FIGS. **2**A and **2**B are diagrams each illustrating an example of how humidity affects the meniscus formed at a transfer unit in transferring a pattern;

[0009] FIG. **3** is a graph illustrating the relation between the humidity of a transfer atmosphere and the thickness of a water film formed on a silicon (Si) transfer substrate;

[0010] FIG. **4** is a diagram illustrating a pattern transfer device according to a first embodiment;

[0011] FIG. **5** is a diagram illustrating a structure of a transfer unit;

[0012] FIG. **6** is a diagram illustrating an example of an alternating current (AC) bias voltage to be applied between the transfer unit and a transfer substrate;

[0013] FIGS. **7**A to **7**F are scanning electron microscope (SEM) pictures illustrating results of pattern transfer under humidity conditions ranging from 40 to 80%;

[0014] FIG. **8** is a diagram illustrating a pattern transfer device according to a first modification of the first embodiment;

[0015] FIG. **9** is a diagram illustrating a pattern transfer device according to a second modification of the first embodiment;

[0016] FIG. **10** is a diagram illustrating a pattern transfer device according to a second embodiment;

[0017] FIG. **11** is a diagram illustrating a pattern transfer device according to a first modification of the second embodiment;

[0018] FIG. **12** is a diagram illustrating a pattern transfer device according to a second modification of the second embodiment; and

[0019] FIG. **13** is a diagram illustrating a pattern transfer device according to a third modification of the second embodiment.

DETAILED DESCRIPTION

[0020] The following describes a pattern transfer device and a pattern transfer method according to embodiments with reference to the accompanying drawings.

[0021] According to one embodiment, the pattern transfer device includes a substrate, a transfer unit and a controller. The transfer unit is configured to have electrodes and transfer a pattern corresponding to the electrodes with a voltage applied between the substrate and the electrodes. The controller is configured to control humidity between the substrate and the transfer unit.

[0022] A typical scanning probe microscope (SPM) lithography that uses a conductive probe can fabricate a high-resolution pattern but with a very low throughput. In recent years, the semiconductor industry has focused on nanoimprint lithography (NIL) as a low-cost lithography technology that can transfer a fine pattern as a whole. In nanoimprint lithography, however, the resolution of the pattern on the master mold defines the resolution of the transferred pattern. To fabricate a high-resolution pattern in nanoimprint lithography, a mold with a very fine pattern is needed, which causes an increase in master cost. In nanoimprint lithography, uniformity of the residual layer and processing on the residual layer still need to be considered. The following describes an example of a technology that is a resist-less technology and can transfer a pattern at higher resolution irrespective of the size of a pattern on a mold.

[0023] As a technology that can achieve a higher resolution than the size of the pattern on the mold, an imprint technology (hereinafter referred to as a sidewall electrode lithography) is known. The sidewall electrode lithography uses a mold (hereinafter referred to as a sidewall electrode mold) including sidewall electrodes for pattern transfer on the side surfaces of protruding structures.

[0024] FIG. **1** illustrates an example of a pattern transfer device including a sidewall electrode mold. In nanoimprint lithography, this pattern transfer device **10** includes a mold **11** having sidewall electrodes **12**, a transfer substrate **13**, and a power source **15**. The sidewall electrodes **12** on the mold **11** are pushed to the transfer substrate **13** and a voltage is applied between the transfer substrate **13** and the sidewall electrodes **12**. With this process, a pattern **14** corresponding to the sidewall electrodes **12** can be formed on the transfer substrate **13**.

[0025] The sidewall electrode lithography is an imprint technology that uses a sidewall electrode mold instead of using a conductive probe. The sidewall electrode lithography can transfer a pattern corresponding to the sidewall electrodes as a whole onto a transferee target by an electrochemical reaction. The sidewall electrode lithography includes a contact method and a contact-less method. In a contact sidewall electrode lithography, the sidewall electrode mold is brought into contact with a target substrate (hereinafter referred to as a transfer substrate) and the pattern formed by the sidewall electrodes is transferred to the transfer substrate. In a contact-less sidewall electrode lithography, portions that form a pattern are kept near the transfer substrate and the pattern is transferred to the transfer substrate. The following mainly describes the contact sidewall electrode lithography, but the following embodiments are also applicable to the contact-less sidewall electrode lithography.

[0026] In the contact sidewall electrode lithography, the contact state between the portions that form a pattern and the transfer substrate may largely affect the transfer characteristic. To uniformly transfer a pattern to the transfer substrate, it is especially important for the sidewall electrodes to be uniformly in contact with the transfer substrate. In the contact-less sidewall electrode lithography, it is especially important to keep a constant space between each sidewall electrode and the transfer substrate to uniformly transfer a pattern.

[0027] In the sidewall electrode lithography, proper control on the humidity of the atmosphere is desired in transferring a pattern to improve the uniformity of the transferred pattern. In terms of material costs and material fabricability, using a mold made of silicon is effective. However, silicon is oxidized by oxygen in the atmosphere. This oxidation forms natural oxides such as SiO_x that are hydrophilic. Thus, when the mold is made of silicon, ends of the protruding portions of the mold that are in contact with or near the transfer surface are hydrophilic. Using a mold having hydrophilic portions that are in contact with or near the transfer substrate forms a larger meniscus at each electrode. This situation may reduce the transfer resolution.

[0028] FIGS. **2**A and **2**B are diagrams each illustrating an example of an effect of the humidity in transferring a pattern with the sidewall electrode mold being pushed onto the transfer substrate. FIG. **2**A illustrates a case when humidity between the transfer substrate and the sidewall electrode mold is 40%, and FIG. **2**B illustrates a case when humidity between the transfer substrate **13** and the sidewall electrode mold **11** is 80%. When the humidity is 80%, a thick water film **18** is formed on the transfer substrate **13** and a larger meniscus **16** is formed at each electrode **12**. In this situation, a larger transfer oxide **17** is formed and the transfer resolution is reduced compared to the case of humidity of 40%.

[0029] FIG. **3** is a graph illustrating the relation between the humidity between the transfer substrate and the sidewall electrode mold and the thickness of the water film formed on the transfer substrate. The thickness of the water film rapidly increases at humidity of 80% or more. However, the humidity of 30% or lower fails to provide enough water to form a pattern, which results in an insufficient pattern formation. To transfer a pattern at a high resolution, the humidity on the transfer substrate needs to be controlled to 30% or more and 80% or less.

[0030] Moreover, the inventors have found that controlling the voltage to be applied between the transfer substrate and the sidewall electrode mold can form a pattern with high aspect ratio.

[0031] The following embodiments describe a pattern transfer device and a pattern transfer method that can prevent a wider linewidth of a pattern caused by the water film on the substrate at a high humidity and can improve the aspect ratio by optimization of transfer voltage conditions.

[0032] The same reference signs indicate the same constituent parts. The drawings are schematic and conceptual ones and thus the relation between the thickness and width and the dimensional ratio between parts in the drawings are not necessarily the same as those in the actual device. The same part may be illustrated in a different dimension or a ratio depending on the drawings.

First Embodiment

[0033] FIG. **4** is a diagram illustrating a pattern transfer device according to a first embodiment.

[0034] This pattern transfer device **1** includes a transfer unit **2** and a transfer unit holder **6** at the transferring side, and a transfer substrate **3**, a humidity controller **4**, and a transfer substrate holder **7** at the transferee side, and includes a power source **5**.

[0035] The transfer unit **2** at the transferring side is attached to the transfer unit holder **6**. The transfer unit holder **6** has, for example, a plurality of suction openings **6*a*** through which the transfer unit **2** is drawn to be held by the transfer unit holder **6**. The transfer unit **2** is not necessarily held by suction. The transfer unit **2** may be held by any method that can stably hold the transfer unit **2**, such as using magnets, a sandwiching tool, or clips. The transfer unit **2** is the aforementioned sidewall electrode mold.

[0036] On the transfer substrate holder **7** at the transferee side, the humidity controller **4** is provided that controls humidity. The transfer substrate **3**, on which a pattern will be transferred, is placed on the humidity controller **4** with a surface (pattern transfer surface) on which the pattern will be transferred facing upwards. The transfer substrate holder **7** has, for example, a plurality of suction openings **7*a*** through which the humidity controller **4** is drawn to be fixed on the transfer substrate holder **7**. The humidity controller **4** has openings **4*a*** that are in communication with at least one of the openings **7*a*** of the transfer substrate holder **7**. With this configuration, the transfer substrate **3** is fixed onto the humidity controller **4** by suction through the openings **7***a* of the transfer substrate holder **7**. The transfer substrate **3** is thus fixed to the transfer substrate holder **7**. The transfer substrate **3** is not necessarily held by suction. The transfer substrate **3** may be held by any method that can stably hold the transfer substrate **3**, such as using magnets, a sandwiching tool, or clips.

[0037] The transfer unit **2** includes a base **2***a*, a plurality of protruding structures **2***b*, and an extraction electrode **2***c* connecting to the protruding structures **2***b*. The transfer unit **2** is held by the transfer unit holder **6** such that a surface **2***d* of each protruding structure **2***b* faces the pattern transfer surface of the transfer substrate **3**. At least one of the transfer unit holder **6** and the transfer substrate holder **7** is movable in the Z direction by a moving mechanism (not illustrated).

[0038] In the first embodiment, the power source **5** is an AC power source. An AC voltage is applied between the extraction electrode **2***c* of the transfer unit **2** and the transfer substrate **3** in transferring a pattern.

[0039] FIG. **5** is a diagram illustrating an example of a contact sidewall electrode mold. The transfer unit **2** includes the base **2***a*, the protruding structures **2***b* and the extraction electrode **2***c*. The base **2***a* is a base member of the transfer unit **2**. The base **2***a* may be made of an insulating material such as silicon or quartz. The base **2***a* may be made of an insulating resin such as polydimethylsiloxane (PDMS) or paraxylene. The base **2***a* may be made of an insulating material having optical transparency.

[0040] The protruding structures **2***b* each have a mesa structure provided on a first main surface **2***e* of the base **2***a*. In FIG. **5**, the protruding structures **2***b* extend in the Y direction on the first main surface **2***e* of the base **2***a* and are arranged at certain intervals in the X direction. However, the arrangement of the structures is not limited to this. The arrangement may be modified in various other forms in accordance with the layout of the pattern to be transferred. The transfer unit **2** may have another structure in which gaps between adjacent protruding structures **2***b* are filled with, for example, a hydrophobic insulating material to make the gaps flush with the protruding structures **2***b*.

[0041] The protruding structures **2***b* each have a protruding portion **2***f*, a functional layer **2***g*, and one or more sidewall electrodes **2***h*. The protruding portion **2***f* has a mesa structure protruding from the first main surface **2***e* of the base **2***a*, and is made of an insulating material such as silicon, quartz, or a resin. The protruding portion **2***f* nay be a machined structure cut out from a bulk base material (for example, a substrate) from which the base **2***a* is formed, or a joined structure attached to the base **2***a*. The protruding portion **2***f* may have a tapered shape to, for example, facilitate fabrication of the protruding portion **2***f* in a fabrication process.

[0042] The functional layer **2***g* covers at least the top end of the protruding portion **2***f* in the Z direction. The functional layer **2***g* has no electrode function, but has a function of providing uniform contact between the sidewall electrodes **2***h* and the target transfer substrate **3**. Thus, the functional layer **2***g* is made of an insulating material that is more deformable than the protruding portion **2***f* (or the base **2***a*). For example, the functional layer **2***g* is made of an insulating material having a Young's modulus of a few to several tens of percent relative to the Young's modulus of the protruding portion **2***f*.

[0043] In the contact sidewall electrode lithography, the functional layer **2***g* is brought into contact with the transfer substrate **3**. Thus, the functional layer **2***g* can have a thickness ranging from a few nanometers (nm) to a few micrometers (μm). In terms of overall contact with the transfer substrate **3** and deformability of the functional layer **2***g*, the thickness of the functional layer **2***g* is preferably 10 nm or more and 10 μm or less.

[0044] The functional layer **2***g* is preferably made of a hydrophobic material to prevent a large meniscus from forming with the water in the atmosphere in transferring a pattern. For example, the functional layer **2***g* is preferably made of a hydrophobic material that has a water contact angle of 45° or more. Examples of the material that satisfies such a requirement include CYTOP (registered trademark), hexamethyldisilazane (HMDS), polymethyl methacrylate (PMMA), polytetrafluoroethylene (PTFE), and Teflon (registered trademark) AF. In terms of ease of processing, using polymethyl methacrylate (PMMA) is preferable. The material of the functional layer **2***g* is not limited to these materials. The material may be any insulating material that is softer than the material of the protruding portion **2***f* and has a higher hydrophobicity than the oxides of the material of the protruding portion **2***f*.

[0045] The functional layer **2***g* is not limited to a single layer structure, but may have a multi-layer structure.

[0046] Although the functional layer **2***g* is described in this context, the functional layer **2***g* is not a necessary element to implement the first embodiment. Thus, the first embodiment includes absence of the functional layer **2***g*.

[0047] The sidewall electrodes **2***h* are structures for transferring a pattern to the transfer substrate **3**. End portions (hereinafter referred to as end surfaces) of the sidewall electrodes **2***h* adjacent to side surfaces of the functional layer **2***g* defines the form of the transferred pattern. The sidewall electrodes **2***h* are made of a conductive material such as a conductive metal or a conductive metal oxide. Examples of the conductive material include Ru, Pt, Rh, W, Ni, Au, Ir, RuO, and IrO_x, but the conductive material is not limited to these.

[0048] The sidewall electrodes **2***h* are each provided on a side surface of the functional layer **2***g* to a side surface of the protruding portion **2***f*. In other words, the sidewall electrodes **2***h* are each provided on a side surface of a protruding structure composed of the protruding portion **2***f* and the functional layer **2***g*.

[0049] The form of the sidewall electrodes **2***h* corresponds to the pattern to be transferred to the transfer substrate as described above. Thus, adjusting the width (corresponding to the thickness of the sidewall electrodes **2***h*) of the end surface of each sidewall electrode **2***h* can adjust the width of a pattern to be transferred to the transfer substrate **3**. The width of the end surface of the sidewall electrode **2***h* may be set to a width narrower than, for example, the width of the protruding portion **2***f* or may be set to a fraction to some tenths of the width of the end surface of the protruding portion **2***f*. For example, the width of the end surface of the sidewall electrode **2***h* may be set to about a few nanometers to several hundreds nanometers.

[0050] The sidewall electrodes **2***h* that form a pattern are preferably positioned at substantially the same height level in the Z direction as that of a surface of the functional layer **2***g* on the side of the transfer substrate **3**. Considering the deformable characteristic of the functional layer **2***g*, the sidewall electrodes **2**h may be positioned at a height level different from the height level of the surface of the functional layer **2**g on the side of the transfer substrate **3** within the range of the deformable characteristic of the functional layer **2**g.

[0051] The extraction electrode **2**c is formed on, for example, a region that is not formed with the protruding structures **2**b on the first main surface **2**e of the base **2**a to a side surface **2**j or to the back surface (a second main surface **2**k opposite to the first main surface **2**e) of the base **2**a. The extraction electrode **2**c is used to electrically draw the sidewall electrodes **2**h. The extraction electrode **2**c connects to an external electrode from which current flows in transferring a pattern to form an electrical connection. The extraction electrode **2**c may be made of a metal such as Al, Cu, W, or Au. The material of the extraction electrode **2**c is not limited to these, but may be a conductive material of various other kinds.

[0052] The transfer substrate **3** is a semiconductor substrate such as a silicon substrate. As described above, the transfer substrate **3** is drawn from the openings **7**a of the transfer substrate holder **7** to be fixed onto the humidity controller **4**.

[0053] The humidity controller **4** controls the humidity between the transfer unit **2** and the transfer substrate **3**. Specifically, the humidity controller **4** includes a sensor (not illustrated) that measures a first temperature and a first humidity of the atmosphere (hereinafter referred to as the atmosphere) between the transfer unit **2** and the transfer substrate **3**, a calculation unit that calculates the dew point of the atmosphere based on the first temperature and the first humidity measured by the sensor, and a temperature control unit that controls the temperature of the transfer substrate **3** to a second temperature based on the dew point so that the humidity near the surface of the transfer substrate **3** will be a certain second humidity. The temperature control unit may be configured by a Peltier device or a heater.

[0054] As the atmospheric temperature drops, water vapor contained in the atmosphere forms water droplets, and the dew point is the temperature below which the water droplets begin to condense.

[0055] The humidity control method implemented by the humidity controller **4** begins with measurement of the first temperature and the first humidity of the atmosphere by the sensor, and then the dew point of the atmosphere is calculated from, for example, a known conversion table. The temperature control unit calculates the second temperature of the transfer substrate **3** based on the calculated dew point. The second temperature is necessary for the second humidity that is the target humidity. When the second temperature is higher than the first temperature, the temperature control unit heats the transfer substrate **3** to the second temperature by using, for example, a Peltier device. When the first temperature measured by the sensor comes closer to the target second temperature, the temperature control unit stops heating. When the first temperature measured by the sensor drops from the second temperature by certain degrees, the temperature control unit may heat the transfer substrate **3** again to keep the temperature at about the second temperature. When the second temperature is lower than the first temperature, the temperature control unit cools the transfer substrate **3** to the second temperature by using, for example, the Peltier device.

[0056] Until dew condensation, moisture content of the atmosphere is unchanged if the temperature changes. At a dew point temperature, humidity of the atmosphere is 100%. Thus, a second temperature T can be calculated based on the moisture content of the atmosphere at the dew point temperature and the moisture content of the atmosphere at a second humidity B.

[0057] Suppose that the dew point temperature obtained from the first temperature and the first humidity is represented by A (° C.), and the second humidity that is the target humidity is represented by B (%), the second temperature T is obtained in the following manner.

[0058] First, a saturated vapor pressure C at the dew point is obtained. The saturated vapor pressure C is obtained by the following expression.

$$C = 6.11 \times 10^{\frac{7.5 \cdot A}{A+237.3}} \tag{1}$$

[0059] A saturated vapor pressure D at the second temperature T is obtained from the second humidity B and the saturated vapor pressure C at the dew point by the following expression.

$$D = C \div B \times 100 \tag{2}$$

[0060] The saturated vapor pressure D at the temperature T is also obtained by the following expression.

$$D = 6.11 \times 10^{\frac{7.5 \cdot T}{T+237.3}} \tag{3}$$

[0061] The following expression is obtained by substituting Expression (1) and Expression (3) for Expression (2) and solving for the temperature T.

$$T = \frac{237.3 \times \log_{10}(E)}{7.5 - \log_{10}(E)} \tag{4}$$
$$E = 10^{\left(\frac{7.5 \cdot A}{A+237.3}+2\right)} \Big/ B$$

[0062] Thus, the second temperature T is obtained by Expression (4).

[0063] The second humidity that is the target humidity near the transfer substrate **3** may be directly input through, for example, a built-in panel provided to the humidity controller **4**, or may be automatically determined by the humidity controller **4** such that the second humidity is kept at, for example, 40% or more and 60% or less. Based on this humidity, the temperature of the transfer substrate **3** may be controlled.

[0064] When, for example, the first temperature and the first humidity of the atmosphere is 25° C. and 80%, respectively, and the second humidity near the transfer substrate **3** is 60%, the second temperature of the transfer substrate **3** is controlled to 29.9° C. For such a dew point and temperature calculation, using a computer or other computing devices is preferred. Such a computing device can perform the aforementioned calculation instantly.

[0065] The temperature of the atmosphere and the surface temperature of the transfer unit **2** and the transfer substrate **3** may be measured by, for example, a thermography.

[0066] According to the results of experiments, controlling the second temperature of the transfer substrate **3** by the humidity controller **4** so that the humidity on the surface of the transfer substrate **3** is kept at 30% or more and 80% or less successfully prevented a large meniscus from forming in transferring a pattern, thereby preventing degradation of transfer resolution. In particular, when the humidity was kept at 40% or more and 60% or less, a precisely controlled pattern was successfully fabricated. When the humidity on the surface exceeded 80%, dew was formed on the transfer substrate **3** as described above, and a large meniscus was formed due to an effect of an excessively formed water film, thereby lowering the transfer resolution. When the humidity on the surface was below 30%, no water film for forming a pattern was formed on the transfer substrate **3**, and no pattern could properly be transferred. The humidity controller **4** may include a power source of its own or may be connected to another power source (not illustrated) that is different from the power source **5** included in the pattern transfer device **1**.

[0067] The power source **5** applies voltage between the transfer unit **2** and the transfer substrate **3**. The voltage to be applied is mainly an AC bias voltage.

[0068] A probe anodic oxidation lithography is known that can improve an aspect ratio of a fabricated pattern by application of an AC bias voltage. Applying the AC bias voltage between the pointed end of a probe and a drawing target can suppress an anodic oxidation in in-plane directions and promote the oxidation in the depth direction, thereby increasing the aspect ratio of the drawn linewidth. Applying a proper AC bias voltage in the sidewall lithography based on the same pattern transfer principle can increase the aspect ratio of the transferred pattern.

[0069] FIG. **6** is a diagram illustrating an example of the AC bias voltage to be applied between the transfer unit **2** and the transfer substrate **3**.

[0070] The vertical axis represents the AC bias voltage and the horizontal axis represents a time. As illustrated in FIG. **6**, the AC bias voltage includes a positive transfer voltage $V_{transfer}$ and a negative set voltage V_{set} relative to the transfer substrate. According to the results of experiments, applying an AC bias voltage instead of a direct current (DC) voltage and setting proper conditions successfully fabricated a high-aspect-ratio pattern having a large thickness and a small width of the pattern.

[0071] As a condition for the AC bias voltage, setting $V_{transfer}$ to a voltage of 1 V or more and 40 V or less can provide voltage necessary for the oxidation and sufficient to keep the oxidation. Setting the AC bias voltage V_{set} to $-V_{transfer}$ or more and smaller than 0 V can cancel the space charge that accumulates at the transferee side. This cancellation can prevent oxidation from proceeding in the horizontal direction, thereby proceeding in the depth direction. Thus, the aspect ratio of the transferred pattern can be improved.

[0072] Setting the frequency of the AC bias voltage to 0.1 Hz or more and 100 Hz or less can fabricate a pattern with a high aspect ratio. A higher frequency forms a meniscus having an unstable shape, which may lead to an unstable pattern transfer. Thus, setting the frequency to 0.1 Hz or more and 100 Hz or less is preferred.

[0073] In transferring a pattern, an electrical potential is applied between the transfer unit **2** and the transfer substrate **3** by the power source **5** with the protruding structures **2*b*** of the transfer unit **2** and the pattern transfer surface of the transfer substrate **3** being in contact with (or close to) each other. The sidewall electrodes **2*h*** cause the water in the meniscus to ionize at contact regions (or close regions) on the pattern transfer surface of the transfer substrate **3**, thereby inducing anodic oxidation on the substrate. This anodic oxidation generates an oxidized pattern having a characteristic different from the characteristic of a region on which no anodic oxidation has occurred.

[0074] When, for example, the transfer substrate **3** is a silicon substrate, silicon atoms (Si) in an electron injection region ionize the water (H_2O) in a meniscus during injection of electrons, and oxygen (O_2) is provided to the electron injection region. The oxygen oxidizes the silicon atoms in the electron injection region and a silicon oxide (SiO_x) is formed thereon. As a result, a silicon oxide film having the same layout as the pattern formed by the sidewall electrodes **2*h*** is formed on the pattern transfer surface of the transfer substrate **3**. Silicon and the silicon oxide have different etch resistance. In other words, etch resistance is one of the characteristics of the oxide generated by the anodic oxidation in this example. The characteristic to be modified is not limited to etch resistance. In other words, the characteristic to be modified may be selected as appropriate depending on the purpose. For example, chemical or physical characteristics (shape, for example) may be modified.

[0075] Described next is an example of a pattern transfer operation of the pattern transfer device **1** according to the first embodiment.

[0076] First, the transfer substrate **3** is placed on the humidity controller **4** provided on the transfer substrate holder **7**. The transfer unit **2** is held by the transfer unit holder **6**. The humidity controller **4** measures the humidity and the temperature between the transfer unit **2** and the transfer substrate **3** to calculate the dew point temperature. The humidity controller **4** changes the temperature of the transfer substrate **3** based on the calculated dew point temperature to control the humidity on the transfer substrate **3** to 40% or more and 80% or less.

[0077] Subsequently, the transfer unit holder **6** moves in the Z direction to bring the protruding structures **2*b*** of the transfer unit **2** into contact with the pattern transfer surface of the transfer substrate **3**, and the protruding structures **2*b*** are pressed against the surface. The state of being in contact with the transfer substrate **3** includes a state in which the surfaces **2*d*** of the transfer unit **2** are directly in contact with the transfer substrate **3** and includes a state in which the surfaces **2*d*** are in contact with the transfer substrate **3** via a water layer.

[0078] The power source **5** applies an AC bias voltage between the transfer unit **2** and the transfer substrate **3**. The AC bias voltage is set so that the aforementioned $V_{transfer}$ is set to 1 V or higher and 40 V or lower and V_{set} is set to higher than $-V_{transfer}$ and lower than 0 V. The frequency of the AC bias voltage is set to 0.1 Hz or higher and 100 Hz or lower. With these settings, the pattern formed by the sidewall electrodes **2*h*** is transferred to the transfer substrate **3**.

[0079] After the pattern is transferred, the transfer unit holder **6** moves in the Z direction to separate the transfer unit **2** from the transfer substrate **3**. If necessary, at least one of the transfer unit **2** and the transfer substrate **3** may be moved to another region to be patterned on the transfer substrate **3** so that the region is formed with the pattern of an anodized film in the same manner. After a pattern is transferred once, the pattern may be transferred a plurality of times on the same area or transferred on the same area in a different orientation to form a layered transferred pattern.

[0080] FIGS. **7**A to **7**F illustrate SEM pictures of transferred patterns transferred by bringing a transfer unit having 30 nm width sidewall electrodes into contact with a Si substrate under the humidity between the transfer unit and the transfer substrate ranging from 40% to 80%.

[0081] An AC voltage of 17 V (with a duty cycle of 50% and a frequency of 1 Hz) was applied between the transfer substrate and the transfer unit for one minute.

[0082] FIG. **7**A illustrates a result of pattern transfer at 80% humidity, and FIG. **7**B is an enlarged diagram of FIG. **7**A. The linewidth of the transferred pattern was as large as a few μm.

[0083] FIG. **7**C illustrates a result of pattern transfer at 60% humidity, and FIG. **7**D is an enlarged diagram of FIG. **7**C. In this case, the linewidth of the transferred pattern was about 40 nm, which was close to 30 nm that was the width of the sidewall electrodes of the transfer unit. FIG. **7**E illustrates a result of pattern transfer under the same conditions as described above except at a reduced humidity of 40%. FIG. **7**F is an enlarged diagram of FIG. **7**E. According to the result of the pattern transfer, the linewidth of the transferred pattern was about 30 nm and the transfer resolution was improved.

[0084] As described above, the pattern transfer device according to the first embodiment controls the humidity between the transfer unit **2** and the transfer substrate **3** to a certain humidity by using the humidity controller **4**, and properly controls the voltage conditions of the power source **5**. This configuration can prevent degradation of resolution of the transferred pattern caused by a high humidity and can form a pattern with a high aspect ratio.

First Modification of First Embodiment

[0085] FIG. **8** is a diagram illustrating a pattern transfer device according to a first modification of the first embodiment.

[0086] The pattern transfer device according to the first modification of the first embodiment differs from the pattern transfer device according to the first embodiment in that the humidity controller **4** is disposed on the upper side of the transfer unit **2**.

[0087] Specifically, the humidity controller **4** is disposed between the transfer unit holder **6** and the transfer unit **2**. The humidity controller **4** has, for example, openings **4***a* that are in communication with at least one of the openings **6***a* of the transfer unit holder **6**. The transfer unit holder **6** fixes the humidity controller **4** by suction from the openings **6***a*. Such a suction operation from the openings **6***a* draws the transfer unit **2** through the openings **4***a* to hold the transfer unit **2**. The transfer unit **2** and the humidity controller **4** are not necessarily held by suction. The transfer unit **2** and the humidity controller **4** may be held by any method that can stably hold the transfer unit **2** and the humidity controller **4**, such as using magnets, a sandwiching tool, or clips.

[0088] The humidity controller **4** changes the temperature of the transfer unit **2** based on the humidity and the temperature on the transfer unit **2** to control the humidity on the transfer unit **2** to a certain humidity.

[0089] Other configurations of the pattern transfer device according to the first modification of the first embodiment are the same as those of the pattern transfer device according to the first embodiment. With these configurations, the pattern transfer device can prevent degradation of a pattern resolution caused by an effect of humidity.

Second Modification of First Embodiment

[0090] FIG. **9** is a diagram illustrating a pattern transfer device according to a second modification of the first embodiment.

[0091] The pattern transfer device according to the second modification of the first embodiment differs from the pattern transfer device according to the first embodiment in that it includes humidity controllers **4** one of which is disposed at the upper side of the transfer unit **2** and the other of which is disposed at the lower side of the transfer substrate **3**.

[0092] Specifically, one humidity controller **4** is disposed between the transfer unit holder **6** and the transfer unit **2**. The other humidity controller **4** is disposed between the transfer substrate **3** and the transfer substrate holder **7**. The humidity controllers **4** are drawn, for example, from the openings **6***a* of the transfer unit holder **6** and from the openings **7***a* of the transfer substrate holder **7** and are fixed thereto. The humidity controllers **4** each have openings **4***a* that are in communication with at least one of the openings **6***a* or are in communication with at least one of the openings **7***a*. The transfer unit **2** and the transfer substrate **3** are drawn from the openings **4***a* and are held by the humidity controllers **4**.

[0093] The humidity controllers **4** may each include a power source of its own or may be connected to a power source (not illustrated) included in the pattern transfer device.

[0094] Other configurations of the pattern transfer device according to the second modification of the first embodiment are the same as those of the pattern transfer device according to the first embodiment.

[0095] Providing the humidity controllers **4** to the transfer unit **2** and the transfer substrate **3** can control the humidity more precisely, thereby preventing degradation of resolution of a pattern caused by an effect of humidity.

Second Embodiment

[0096] FIG. **10** is a diagram illustrating a pattern transfer device according to a second embodiment.

[0097] The pattern transfer device according to the second embodiment differs from the pattern transfer device according to the first embodiment in that it includes a control chamber **8** instead of the humidity controller **4**.

[0098] The transfer unit **2**, the transfer substrate **3**, the transfer unit holder **6**, the transfer substrate holder **7**, and the power source **5** are disposed inside the control chamber **8**. The control chamber **8** may be, for example, a commercially available thermostatic chamber or an environment test chamber. The control chamber **8** controls the humidity in the chamber so that the humidity between the transfer unit **2** and the transfer substrate **3** is kept at a certain humidity. The power source **5** is not necessarily disposed inside the control chamber **8**. Wires from the transfer unit **2** and the transfer substrate **3** may be extended to the outside of the control chamber **8**, at which the power source **5** may be connected to the wires. Other configurations of the pattern transfer device according to the second embodiment are the same as those of the pattern transfer device according to the first embodiment.

[0099] The pattern transfer device according to the second embodiment can stably control the humidity during pattern transfer by using the control chamber **8** irrespective of the ambient temperature or humidity.

First Modification of Second Embodiment

[0100] FIG. **11** is a diagram illustrating a pattern transfer device according to a first modification of the second embodiment.

[0101] The pattern transfer device according to the first modification of the second embodiment differs from the pattern transfer device according to the second embodiment in that it includes both the humidity controller **4** and the control chamber **8**.

[0102] The humidity controller **4** is disposed between the transfer substrate **3** and the transfer substrate holder **7**. The humidity controller **4** has, for example, openings **4***a* that are in communication with at least one of the openings **7***a* of the transfer substrate holder **7**. The transfer substrate holder **7** fixes the humidity controller **4** by suction from the openings **7***a*. Such a suction operation from the openings **7***a* draws the transfer substrate **3** through the openings **4***a* to hold the transfer substrate **3**.

[0103] The pattern transfer device according to the first modification of the second embodiment does not necessarily completely control the humidity in the control chamber **8** to a stable humidity. The target humidity to be controlled is the humidity between the transfer unit **2** and the transfer substrate **3**. Thus, the control chamber **8** may control the humidity to some extent and the humidity controller **4** may control the humidity to a certain stable humidity.

[0104] As described above, using both the control chamber **8** and the humidity controller **4** can reduce the frequency of changing the temperature of the transfer unit **2** or the transfer substrate **3** by a large degree, thereby reducing the time for controlling the humidity to a certain stable humidity. The humidity in the control chamber **8** may be at the same humidity level as that in typical clean rooms (50 to 60%). The humidity in the control chamber **8** can be changed as appropriate in accordance with the target humidity between the transfer unit **2** and the transfer substrate **3**.

Second Modification of Second Embodiment

[0105] FIG. **12** is a diagram illustrating a pattern transfer device according to a second modification of the second embodiment.

[0106] The pattern transfer device according to the second modification of the second embodiment differs from the pattern transfer device according to the first modification of the second embodiment in that the humidity controller **4** is disposed between the transfer unit **2** and the transfer unit holder **6**. Other configurations of the second modification of the second embodiment are the same as those in the first modification of the second embodiment.

Third Modification of Second Embodiment

[0107] FIG. **13** is a diagram illustrating a pattern transfer device according to a third modification of the second embodiment.

[0108] The pattern transfer device according to the third modification of the second embodiment differs from the pattern transfer device according to the other modifications or embodiments in that it includes the control chamber **8** and two humidity controllers **4** one of which is disposed between the transfer unit **2** and the transfer unit holder **6** and the other of which is disposed between the transfer substrate **3** and the transfer substrate holder **7**. Other configurations of the third modification of the second embodiment are the same as those in the second embodiment.

[0109] As mentioned above, the control chamber **8** does not necessarily precisely control the humidity to the target humidity. The control chamber **8** may control the humidity to some extent and the humidity controllers **4** may control the humidity to a certain stable humidity.

[0110] Using the control chamber **8** can reduce the frequency of changing the temperature of the transfer unit **2** or the transfer substrate **3** by a large degree. This configuration can reduce the time for controlling the humidity to a certain stable humidity. In addition, providing two humidity controllers **4** can precisely control the humidity between the transfer unit **2** and the transfer substrate **3** and the humidity near the surfaces thereof.

[0111] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A pattern transfer device comprising:
- a substrate;
- a transfer unit having electrodes, the transfer unit being configured to transfer a pattern corresponding to the electrodes with a voltage applied between the substrate and the electrodes; and
- a controller configured to control humidity between the substrate and the transfer unit.

2. The pattern transfer device according to claim **1**, wherein
- the transfer unit includes a plurality of protruding portions facing the substrate, and
- the electrodes are each disposed on a sidewall of the respective protruding portions.

3. The pattern transfer device according to claim **1**, wherein the voltage is an alternating current (AC) voltage.

4. The pattern transfer device according to claim **3**, wherein, when a maximum voltage of the AC voltage is represented by Vmax, the Vmax is 1 V or higher and 40 V or lower.

5. The pattern transfer device according to claim **4**, wherein, when a minimum voltage of the AC voltage is represented by Vmin, the Vmin is higher than –Vmax and lower than 0 V.

6. The pattern transfer device according to claim **3**, wherein the AC voltage has a frequency of 0.1 Hz or higher and 100 Hz or lower.

7. The pattern transfer device according to claim **1**, wherein the controller keeps the humidity between the substrate and the transfer unit at 30% or more and 80% or less.

8. The pattern transfer device according to claim **1**, wherein the controller is disposed at a lower side of the substrate or at an upper side of the transfer unit.

9. The pattern transfer device according to claim **1** further comprising:

a control chamber that contains the substrate, the transfer unit, and the controller, wherein

the control chamber controls a humidity or a temperature inside the control chamber.

10. A pattern transfer device comprising:

a substrate;

a transfer unit having electrodes, the transfer unit being configured to transfer a pattern of the electrodes; and

a control chamber containing the substrate and the transfer unit, the control chamber being configured to control humidity, wherein

the pattern of the electrodes is transferred onto the substrate with a voltage applied between the substrate and the electrodes.

11. A pattern transfer method employed in a pattern transfer device including a substrate, a transfer unit having electrodes, the transfer unit being configured to transfer a pattern of the electrodes, and a controller configured to control humidity between the substrate and the transfer unit, the pattern transfer method comprising:

bringing the electrodes of the transfer unit into contact with the substrate;

controlling the humidity between the substrate and the transfer unit by the controller; and

transferring the pattern of the electrodes onto the substrate by applying a voltage between the substrate and the electrodes.

12. The pattern transfer method according to claim **11**, wherein

the voltage is an AC voltage, and

when a maximum voltage of the AC voltage is represented by Vmax, the Vmax is 1 V or higher and 40 V or lower.

13. The pattern transfer method according to claim **12**, wherein

the voltage is an AC voltage, and

when a minimum voltage of the AC voltage is represented by Vmin, the Vmin is higher than −Vmax and lower than 0 V.

14. The pattern transfer method according to claim **11**, wherein the controlling includes keeping the humidity between the substrate and the transfer unit at 30% or more and 80% or less by the controller.

* * * * *